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Calibration of Pitot Tubes

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CALIBRATION OF PITOT TUBES

...BY...

John Frederick Peterson

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1904

May 27, 1904

This is to certify that the following thesis, prepared under the direction of Professor A. N. Talbot, Head of the Department of Municipal and Sanitary Engineering, by JOHN FRED PETERSON, entitled CALIBRATION OF PITOT TUBES, is accepted by as fulfilling this part of the requirement for the degree of Bachelor of Science in Civil Engineering.

Ira O. Baker

Head of the Department of Civil Engineering.

P44

The Calibration of Pitot Tubes.

The Pitot tube was invented by Pitot in 1730. It consisted simply of a glass tube bent at right angles, and its mouth was placed so as to directly face the current, the velocity of which it was desired to measure. The water then rose to a height, h. in the vertical part of the tube giving a measure of the velocity according to the formula $v = \sqrt{2gh}$. Later a second tube was added, having an opening at the bottom, so that when one opening was opposed to the current the other was perpendicular to it.

Later the instrument was improved by Darcy and Bazin. They used two tubes, one drawn to a fine point and pointing up stream; the other was provided with small holes on the top and bottom. The tops of the two tubes were connected so that a partial vacuum formed above

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the liquid causing it to rise to a height convenient for reading. The results of the experiments by D'arcy and Bazin were published in 1865. They found that, for the tube described, using the formula $v = c\sqrt{2gh}$, c was approximately equal to unity.

For a long time after this little was done with this device, it being regarded as an instrument of a low degree of precision.

In 1888 Freeman (Transactions of American Society Civil Engineers. 1889. vol. 21). used an improved form of Pitot tube in some experiments on the velocities of jets from nozzles. The point of the tube facing the current was the tip of a stylographic pen, the diameter of the opening being about 0.006-inches. This tube was introduced into different parts of the jet, and the pressure caused in the tube was measured by a Bourdon pressure gauge. Velocities as high as 87 feet per second were measured in

this manner; and, by comparing with the measured discharge, Freeman concluded that the velocity determined from the Pitot tube, varied from the actual velocity by less than one per cent.

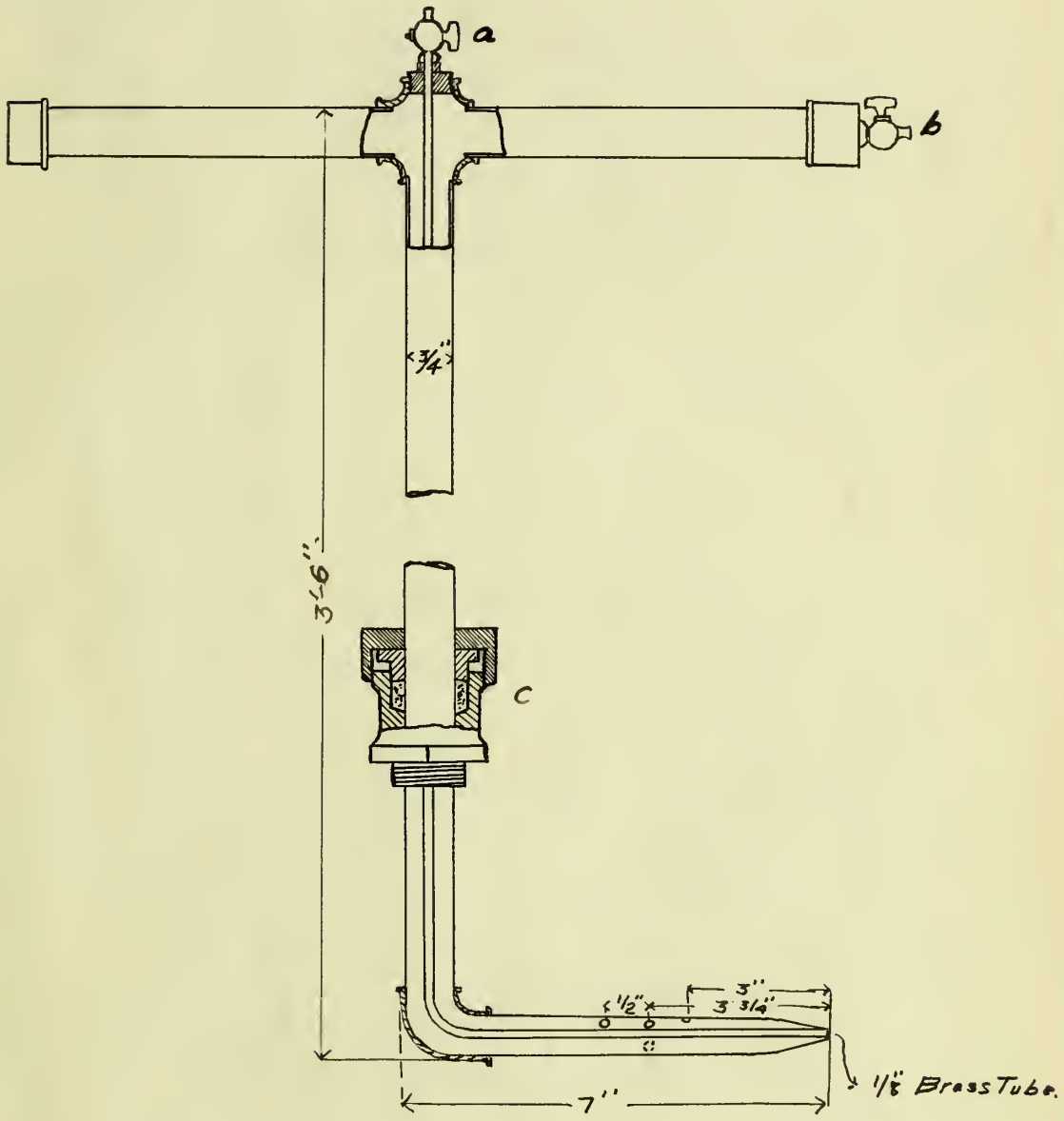
In 1897 experiments on the flow of water in pipes, were made by Cole at Terre Haute, Ind., and, in 1898, by Williams, Hubbell and Fenkel at Detroit. (Transactions American Society Civil Engineers 1902, vol. 47). All of these experiments established the fact that the Pitot tube is an instrument of great precision for the measurement of velocities of water.

The experiments which are to be described in this thesis were suggested by Assistant Engineer F. B. Maltby, of the Mississippi River Commission. In 1902 Mr. Maltby made a series of efficiency tests on the hydraulic dredges used by the Mississippi River Commission, and used Pitot tubes for determining the velocities of flow in the discharge and suction

pipes of the dredges. These pipes ranged in size from 16 to 34 inches, and velocities through them of from 6 to 25 feet were measured. Several Pitot tubes were made and their coefficients determined. The ones used, which were found to have a coefficient of unity, were of similar construction to the one used in these tests, the difference being that larger pipe were used in the first mentioned, and the portion which points in the direction of the stream was about one foot longer than that of the tube used in these experiments.

For the following experiments the 12-in., 8-in, and 6-in. pipes in the Hydraulic Laboratory of the University of Illinois were used. These pipes are all connected to the 60-ft. standpipe in the laboratory and are also connected to the two pumps which are located directly over a sump in the north-east corner of the building. The pumps used for supplying water for low velocities and for pumping into the

FIG. 1.



stand-pipe is a Stillwell-Bierce duplex direct-acting pump. The pump used for high velocities is a 6-in. centrifugal pump.

The pipes all discharge back into the sump through a channel along the north side of the laboratory. In this channel are two weirs. The upper weir is 3 feet across, and has end contractions. The lower one is also 3 feet wide, with suppressed end contractions. Both of these weirs were calibrated by A. C. Le Sourd, U. of I. '03, (Calibration of Weirs in the Hydraulic Laboratory of the University of Illinois. Thesis - University Library.), and his results for the suppressed weir were used in measuring the discharge from the pipes, in these experiments. Each pipe was tapped with two holes to admit the Pitot tube; one at the side of the pipe and one at the bottom.

The Pitot tube used is shown in Fig 1. p. 5. It consists of an outside 3/4-in. pipe and an inner 1/8-in. tube. The upstream end of the

outer tube tapers down so as to enclose the end of the inner tube, forming the impact point. This tube runs inside the large pipe to the top where it is connected to a 1/4-in. cock. The horizontal pipe has four 1/16-in. holes drilled in its side for determing the static pressure, the interior of the pipe being connected through the upright pipe and the handle to another 1/4-in. cock (b). Each of these cocks is connected by rubber tubing to the differential gauge.

The stuffing box arrangement is shown at c. The stuffing box is screwed into the holes tapped in the pipe and the tube can be moved through this stuffing box to the position desired.

For the purpose of measuring the pressure, a differential gauge was used. This consisted of a 1/4-in. glass U tube about 3 feet long connected by rubber tubing to the Pitot tube. The U tube was half filled with carbon tetrachloride, a colorless liquid having a specific gravity of 1.60. (This value

was found by frequent trials to remain constant throughout the tests.). Since the specific gravity of the liquid is different from that of water it is necessary to determine the head of water which corresponds to the actual head as read on the gauge. If h' equals the head read from the gauge, h, the corresponding water head, and x, the specific gravity of the liquid, then $h = h'x - h'$ or $h = h'(x-1)$.

Since the velocity of water through a pipe varies at different parts of the cross-section it is necessary to determine the mean velocity. In these experiments this was accomplished by placing the point of the Pitot tube at points across the tube and recording the gauge readings. From these readings a curve was plotted giving the relative velocities at different points across the pipe. The pipe was then divided into concentric circular rings of equal area, and the velocity found at the middle point of each of these annular areas. The mean

FIG. 2.

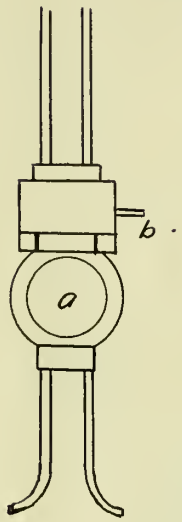
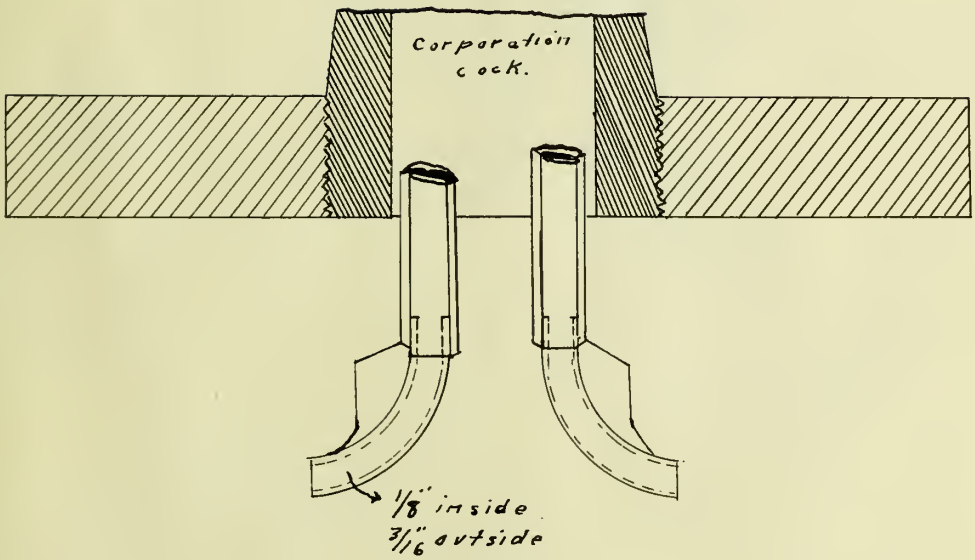


FIG. 3.



of these velocities was then computed and this mean was taken as the mean velocity.

In making these traverses across the pipe with the Pitot tube it was found that the point of the instrument could not be brought within about 1/2-in. of the inside of the pipe. This left an important area untraversed and made it impossible to determine the character of the velocity curve. It also left the value of the mean velocity subject to considerable error. To remedy this a Cole — Flad pitometer was used.

A drawing of the Cole-Flad pitometer is shown on page 9. It consists of two tubes which pass through a special corporation cock (a) designed for this purpose. The tubes are bent at the ends which enter the pipe and one point is turned up stream and the other downstream, when making tests. The connection with the differential gauge is made in the same manner as described with the other tube. At (b) (Fig 2.) is an opening leading to the air

which can be connected to a pressure-gauge, so that the water pressure can be read at the same time deflections are being noted.

This pitometer was calibrated by G. L. Sawyer, U of C. '03, (Calibration of Cole-Flad Pitometer. Thesis -- University Library). Mr. Sawyer used an open channel placing the openings of the pitometer in the center of the channel, and used floats for determining the velocity of the water. He obtained a coefficient of 0.80 for this instrument.

With this pitometer traverses of the different pipes were made to determine the form of the velocity curve. For one inch from the wall of the pipe readings were taken every 1/4 inch. On plotting the square roots of the readings thus obtained it was found that the resulting curve approximates an ellipse very closely, and hence in these experiments the velocity curve was considered to be an ellipse.

Considerable difficulty was en-

countered in getting the air out of the instrument when making a test. The best method to overcome this trouble was found to be as follows.— After the tube had been inserted in the pipe, the pipe was filled with water, and the rubber tubes were connected to the cocks. The cocks were then opened and water allowed to flow through forcing the air out with it. While the water was flowing, the connection was made with the differential gauge. By this method the air had no opportunity to enter the apparatus. The liquid was then brought to the same level in both arms of the V tube. By opening cocks connected to the rubber tubes and the apparatus was then ready.

To simplify computations of results a constant was deduced which multiplied by the square root of the gauge reading in inches would give the velocity as registered by the gauge. Thus in $v = \sqrt{2gh} = \sqrt{64.32h}$, but h must be

changed to the equivalent water head which for a specific gravity of 1.60 equals 0.6 h, hence $v = \sqrt{64.32 \times \frac{.64}{12}}$ (h being in inches) = $1.79\sqrt{h}$.

Plates I and II. show the elliptical character of the velocity curve as obtained by using the Cole-Pitot tube pitometer.

Plates III and IV show the velocities as obtained from traversing the 8 in pipe. In these plates the curves show the actual velocities as indicated by the gauge.

Plate V gives the results obtained with the 6-in. pipe. On this plate the value of $\sqrt{h}$ was plotted and the velocity at any point may be found by multiplying the value of $\sqrt{h}$ by 1.79.

Plate VI gives the results with the 12-in. pipe. Here also the values of $\sqrt{h}$ were plotted.

All of these results are also shown in tabular form.

As seen from the results the coefficients vary from .92 to 1.03. The extreme variation is considerable and the probable error of the average value of the coefficient

may be rather large. There are two things which may cause error in these observations. The flow through the pipe during a test may not have been uniform, and the measurement of the discharge may have been inaccurate.

The flow through the pipe, when the Stillwell-Bierce pump was used was kept uniform by keeping a constant head on the stand pipe. When the centrifugal pump was used water was pumped directly into the pipe. In either case the point of the hook gauge was set at the surface of the water in the channel before a test was started, and watched throughout the test. If there was any noticeable change in the head of water on the weir the test was rejected.

The head on the weir was carefully measured, and as the weir has been carefully calibrated, the chance for error here seems small.

Taking these things into consideration, it is believed that the tests recorded are quite accurate and that 0.95

is a fair value for the coefficient of this Pitot tube.

PLATE I.

Curves showing values of $\sqrt{h}$ using Cole-Flad Pitometer.

6-in. pipe.

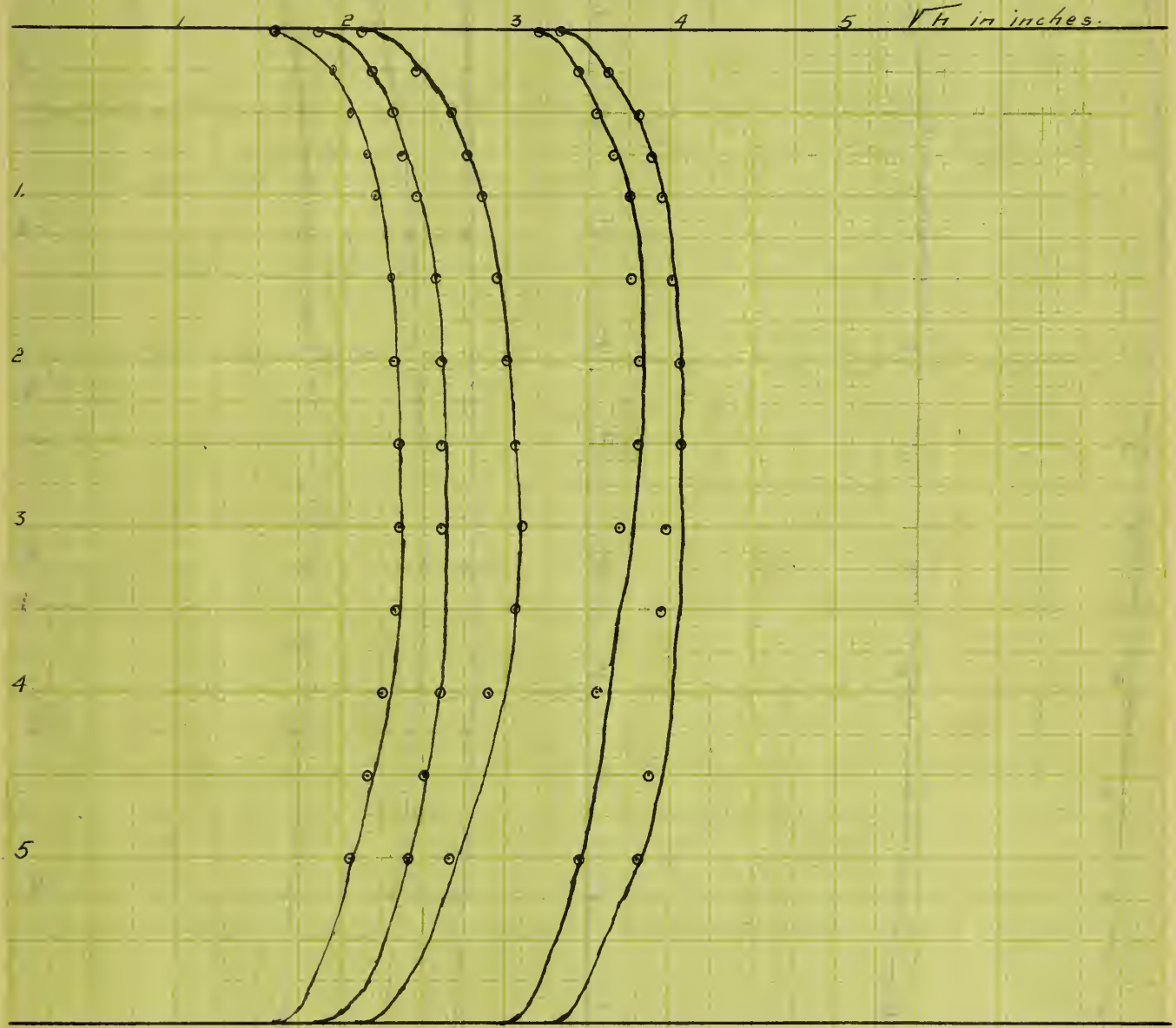


PLATE I.

Curves showing values of $P\frac{R}{t}$ using

Cole-Fred Piezometer.

8-in. pipe.

PLATE II.

Curves showing values of $\sqrt{h}$ using Cole-Flad Pitometer.

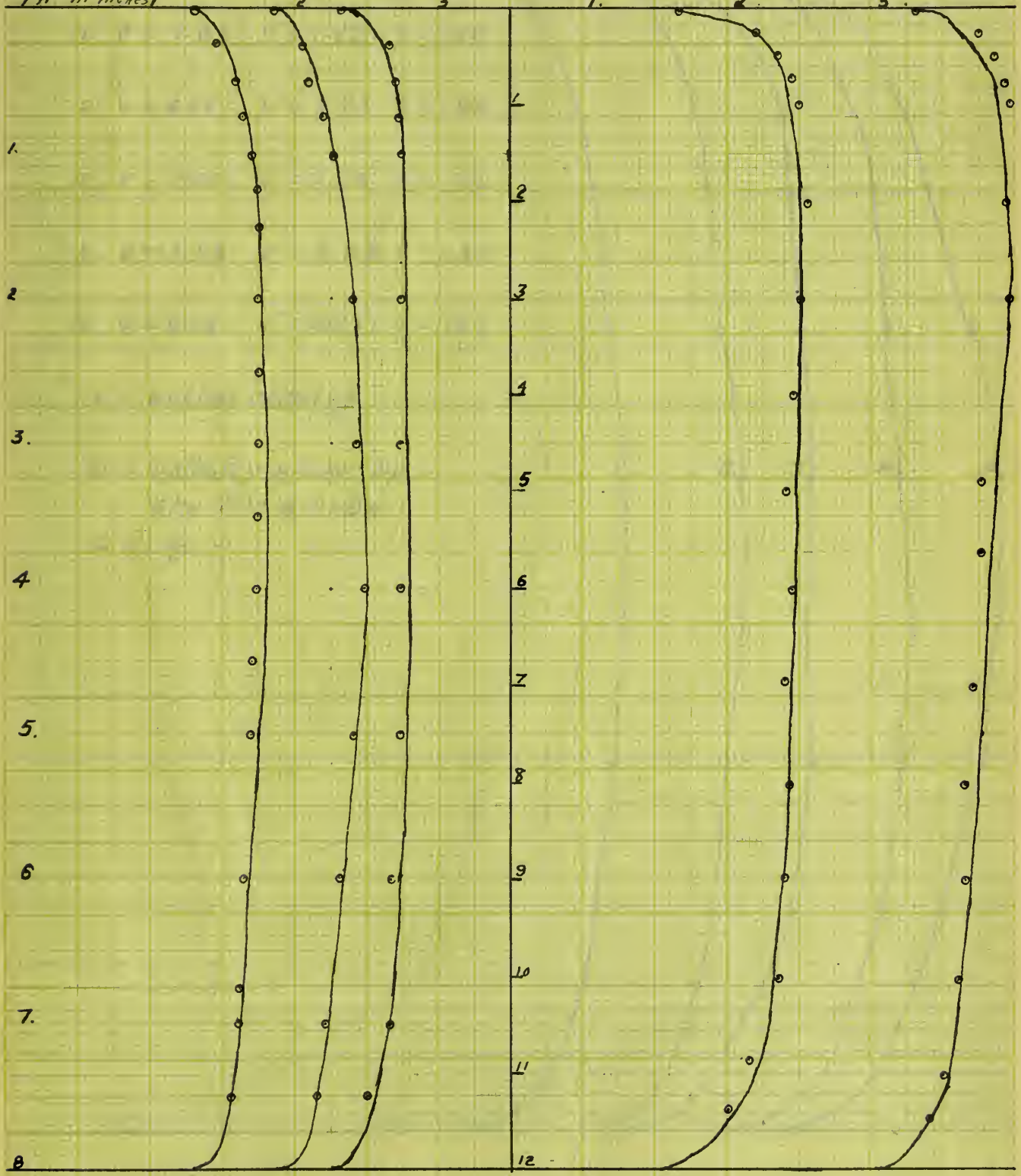


PLATE II

Curves showing values of Th using
Cole-Flad Pitometer

PLATE III.

RESULTS WITH 8-IN. PIPE.

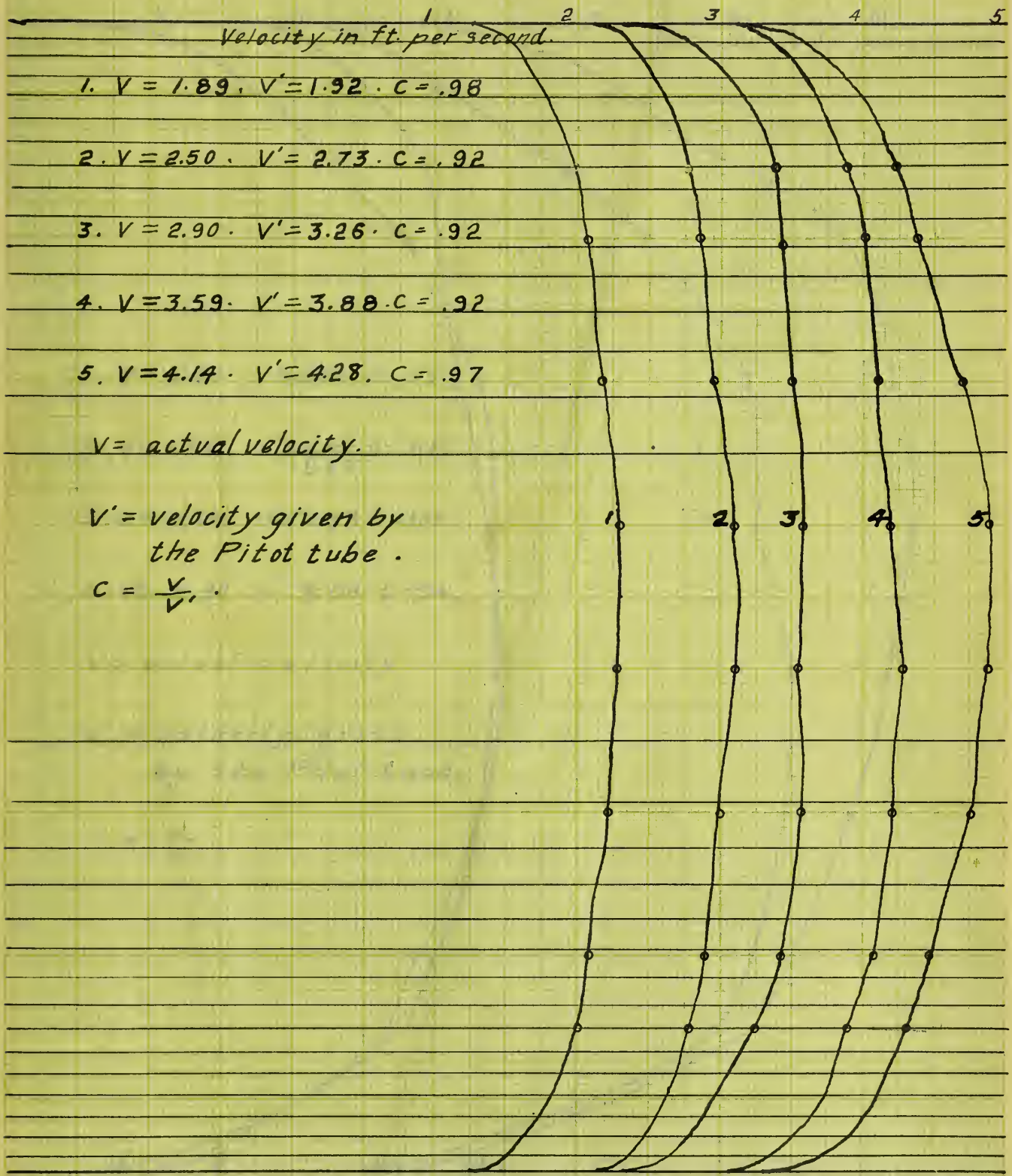

1
2
3
4
5
Velocity in ft. per second.
1. V = 1.89 . V' = 1.92 . C = .98
2. V = 2.50 . V' = 2.73 . C = .92
3. V = 2.90 . V' = 3.26 . C = .92
4. V = 3.59 . V' = 3.88 . C = .92
5. V = 4.14 . V' = 4.28 . C = .97
V = actual velocity.
V' = velocity given by the Pitot tube.
C = V/V'.
1
2
3
4
5

PLATE III

RESULTS WITH 8-IN. PIPE.

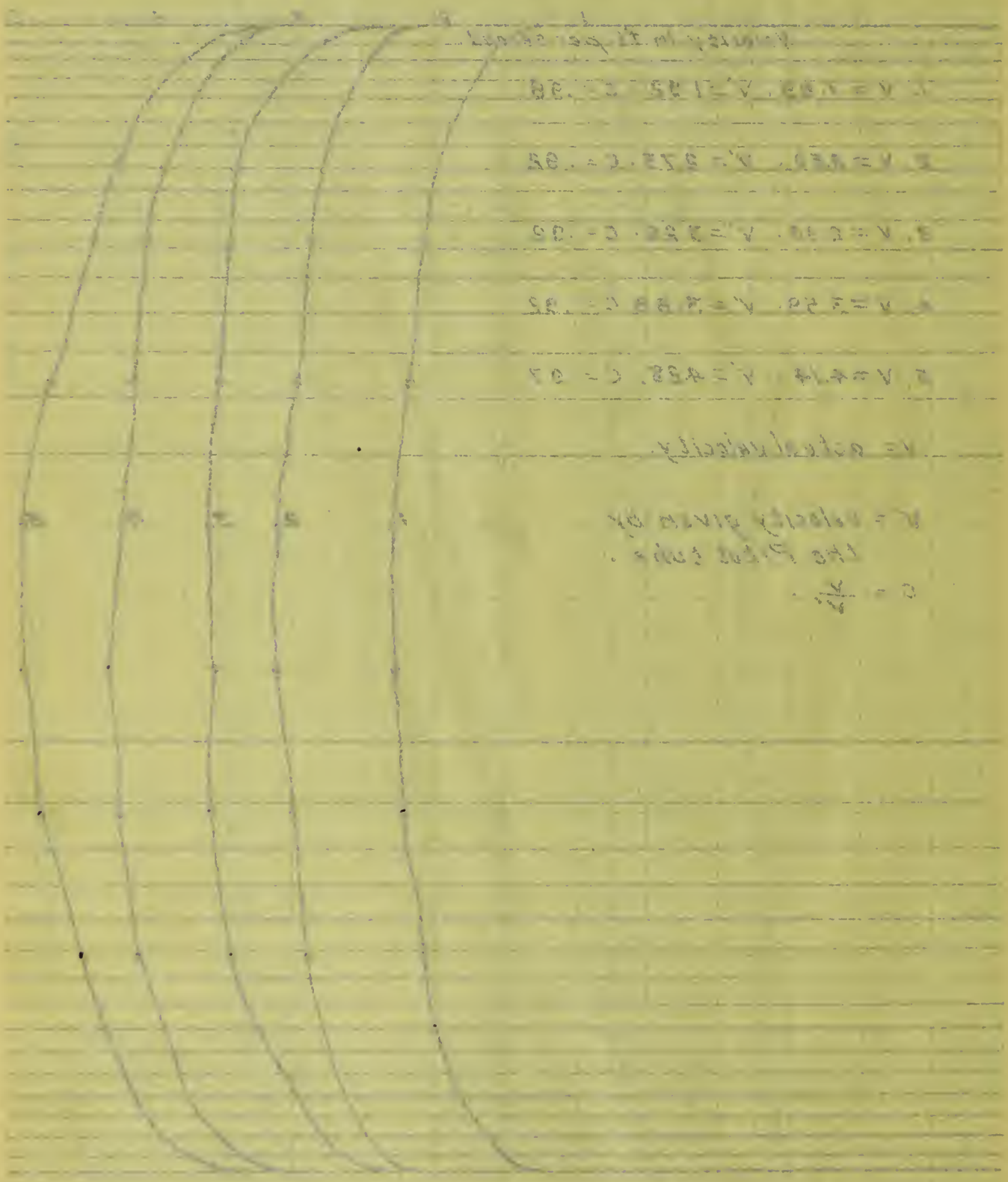
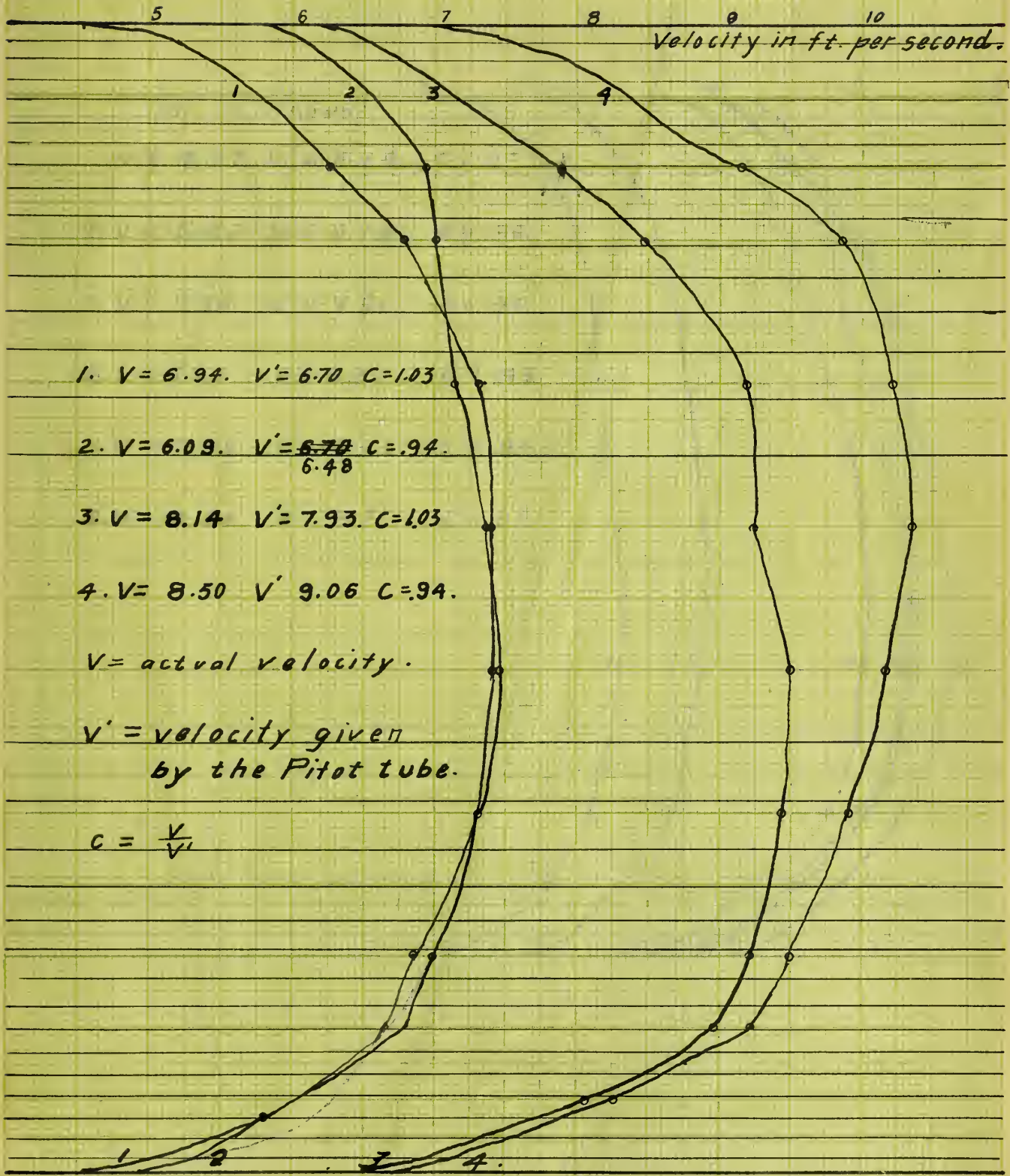


PLATE IV.

RESULTS WITH 8-IN. PIPE.



1. V = 6.94. V' = 6.70 C = 1.03

2. V = 6.09. V' = ~~6.70~~ 6.48 C = .94.

3. V = 8.14 V' = 7.93. C = 1.03

4. V = 8.50 V' 9.06 C = .94.

V = actual velocity.

V' = velocity given by the Pitot tube.

$C = \frac{V}{V'}$

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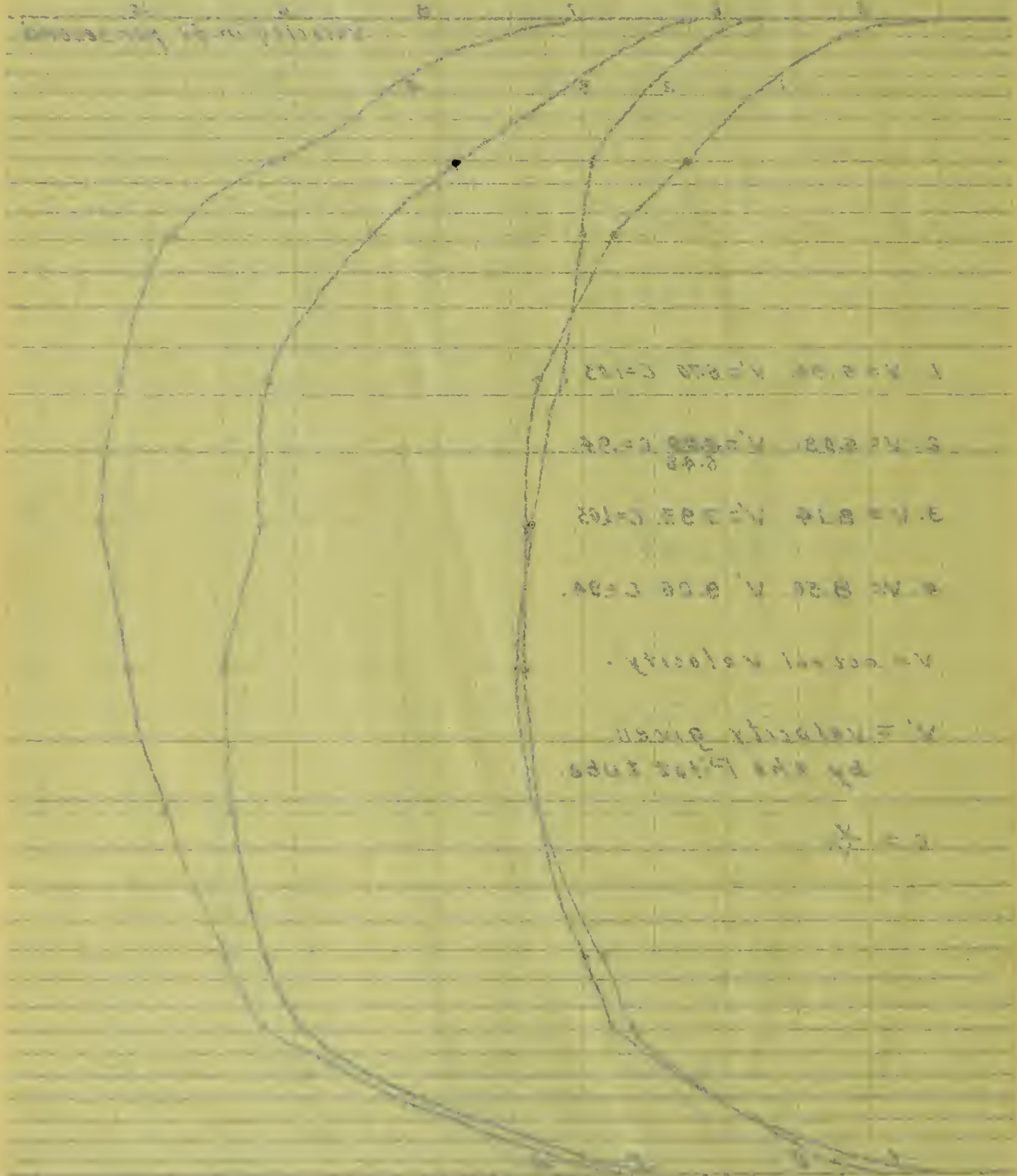


PLATE V.

RESULTS WITH 6-IN. PIPE.

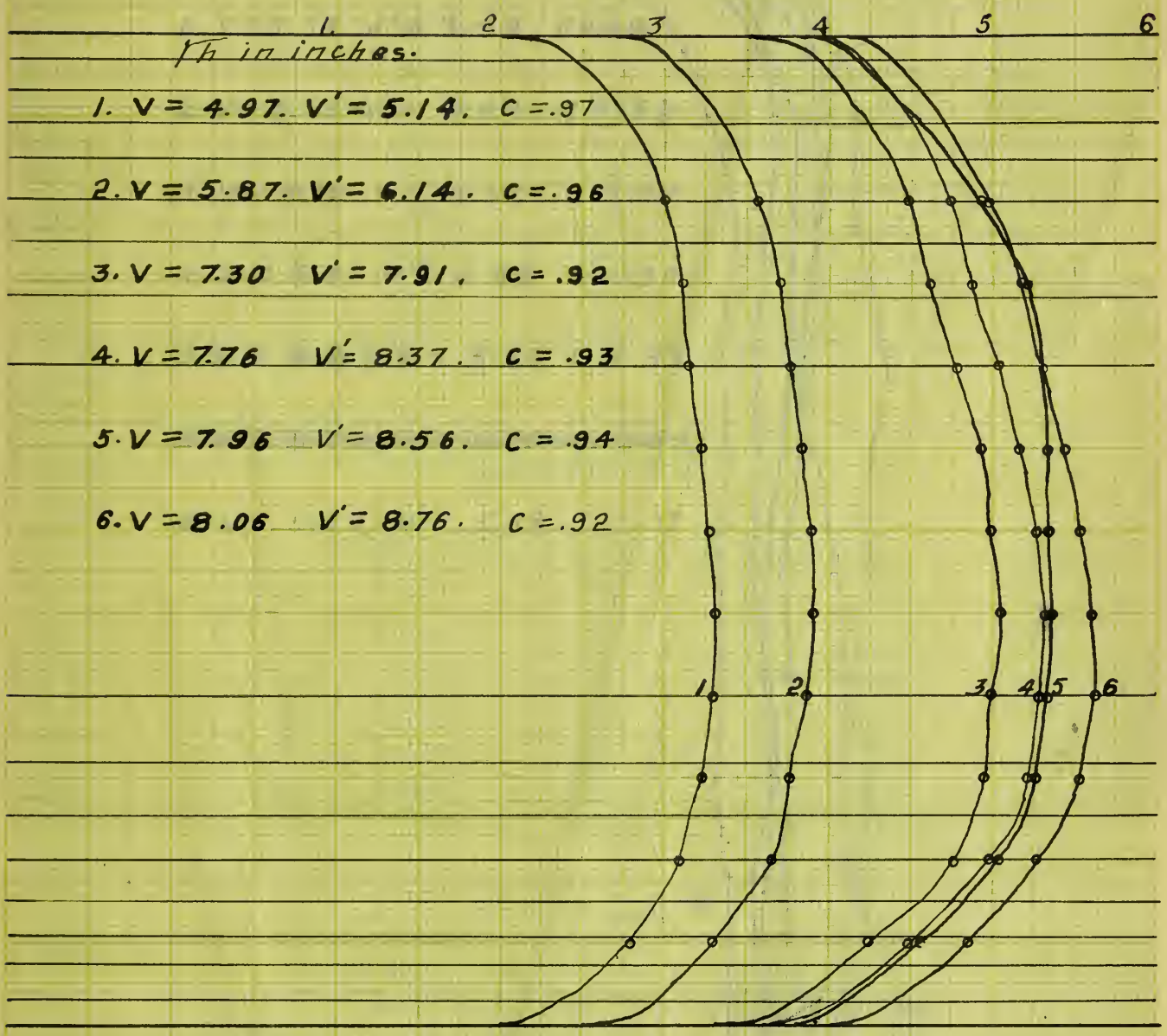


PLATE V.

RESULTS WITH 8-IN. PIPE.

PLATE VI.

RESULTS WITH 12-IN. PIPE.

Vh in inches. 1 2 3 4

1. V = 3.90. V' = 3.99. C = .98

2. V = 4.23 V' = 4.60 C = .92

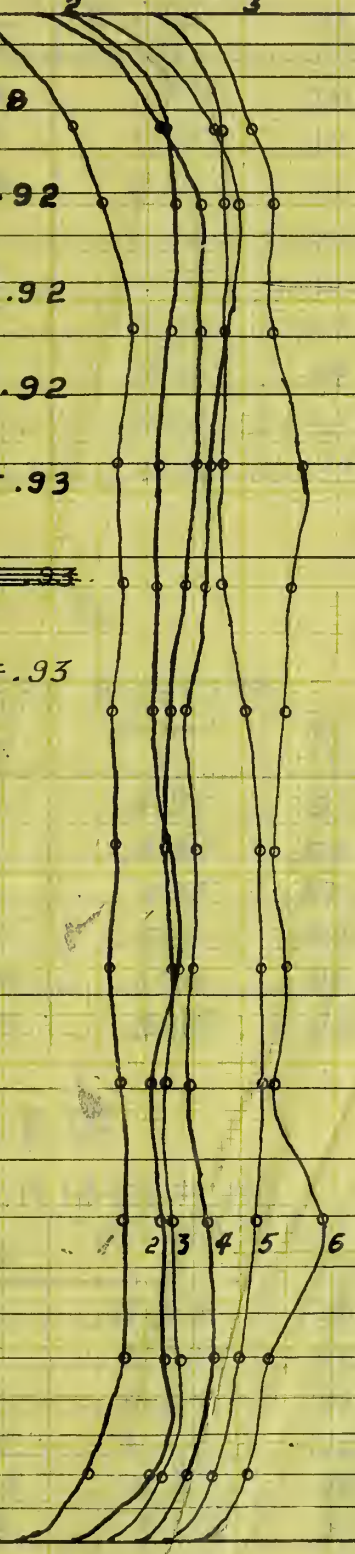
3. V = 4.30 V' = 4.67 .C = .92

4. V = 4.61 V' = 4.99 C = .92

5. V = 4.87. V' = 5.23. C = .93

~~5. V = 5.98. V' = 6.44. C = .93~~

6. V = 5.29 V' = 5.69. C = .93



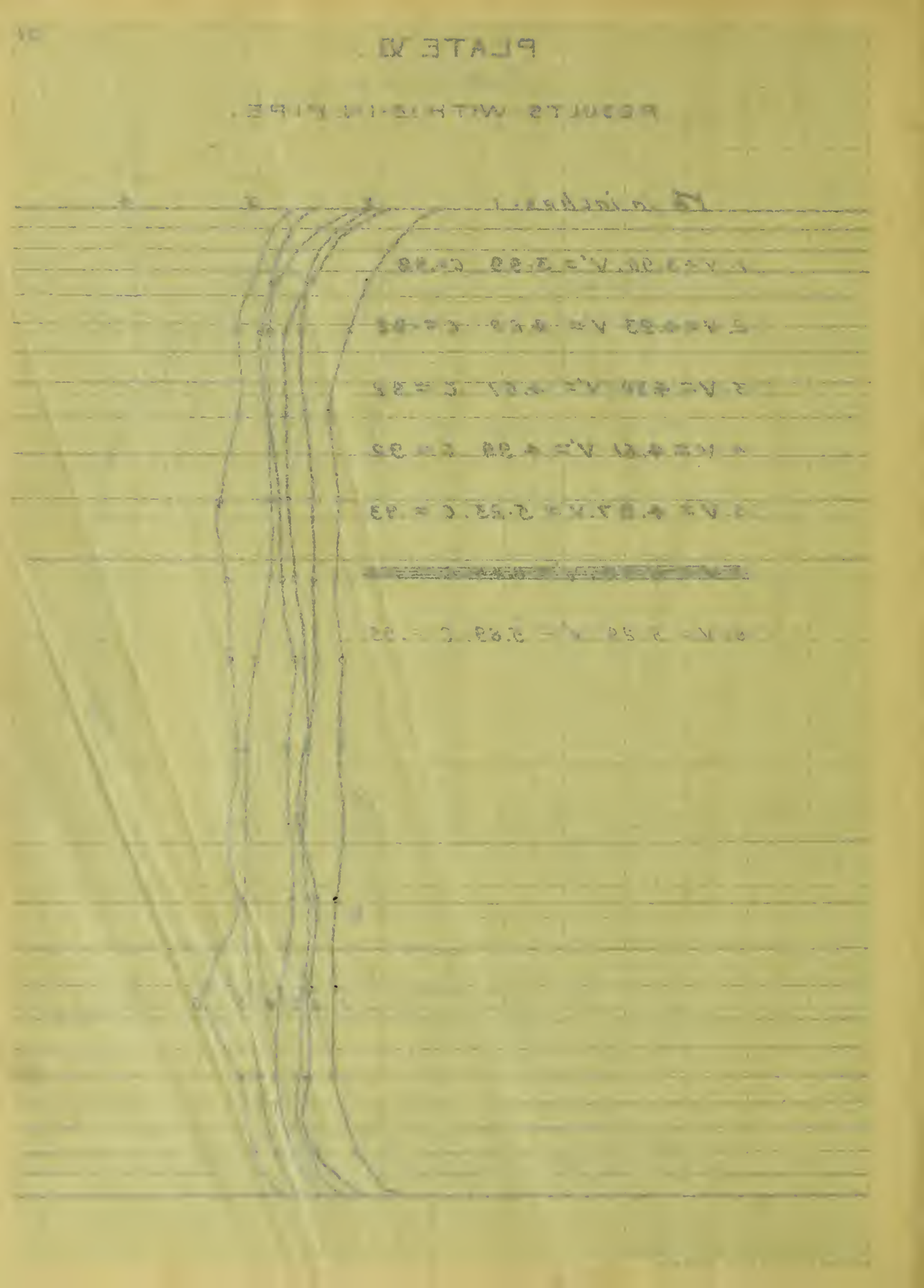


TABLE I.

RESULTS WITH 8-IN. PIPE.

No.	Mean $\sqrt{h}$	$V' = 1.79 \times \sqrt{h}$	Actual V.	V/V'
1.	1.07	1.92	1.89	.98
2.	1.52	2.73	2.50	.92
3.	1.82	3.26	2.90	.92
4.	2.17	3.88	3.59	.92
5.	2.39	4.28	4.14	.97
6.	3.73	6.70	6.94	1.03
7.	3.80	6.48	6.09	.94
8.	4.43	7.98	8.14	1.03
9.	5.06	9.06	8.50	.94

TABLE II.

RESULTS WITH 6-IN. PIPE.

No	Mean $\sqrt{h}$	$V' = 1.79 \times \sqrt{h}$	Actual V.	V/V'
1	2.87	5.14	4.97	.97
2	3.43	6.14	5.87	.96
3	4.42	7.91	7.30	.92
4	4.70	8.37	7.76	.93
5	4.78	8.56	7.96	.94
6	4.89	8.76	8.06	.92.

TABLE III.

RESULTS WITH 12-IN PIPE.

No	Mean $\sqrt{h}$	$V' = 1.79 \times \sqrt{h}$	Actual V	V/V'
1.	2.23	3.99	3.90	.98
2.	2.57	4.60	4.23	.92
3.	2.61	4.67	4.30	.92
4.	2.79	4.99	4.61	.92
5.	2.92	5.23	4.87	.93
6	3.18	5.69	5.29	.93

Mean c = .948.

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